3.3 Vadose Zone Characterization and Monitoring

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Historically, radionuclides were released into the vadose zone sediment (the unsaturated sediment between the ground surface and the top of the unconfined ground-water aquifer) at the Hanford Site through several hundred effluent discharge facilities (e.g., cribs, ditches) and as a result of leaks and spills from single-shell radioactive waste storage tanks. These discharges, leaks, and spills represent the largest quantity of long-lived (half-life >3 years) radioactive contamination released to the environment from site operations.

In 1996, two programs were under way to characterize and monitor gamma-emitting radionuclides in the vadose zone: one focused on vadose zone monitoring near single-shell radioactive waste tanks; the other involved monitoring near historical effluent disposal sites, which include cribs, ponds, ditches, injection wells, and french drains. The low- and intermediate-level wastes released at the historical effluent disposal facilities may be of greater concern than the high-level contamination leaked or spilled from the tanks because of the large liquid volume associated with these discharges. The large fluid volume could move contaminants deep into the vadose zone and close to the groundwater.

Both programs were designed to characterize and monitor gamma-emitting radionuclides in the vadose zone and focus primarily on establishing existing baseline conditions with minimal emphasis on true monitoring aspects. Once a baseline is established for a particular tank or effluent discharge facility, it can be monitored for either long-term or short-term changes. The intent of long-term monitoring is to detect changes over a 5- to 10-year period that can be used for predictive risk assessments. Short-term monitoring is used to identify recent changes in the vadose zone caused by current operations or tank leaks.

At all vadose zone monitoring and characterization locations, borehole geophysical logging methods were used to obtain information about the distribution of gamma-emitting radionuclides and moisture in existing boreholes. Logging methods were used because they are the most economical means of obtaining information about conditions in the subsurface. For comprehensive characterizations or special investigations, follow-up drilling and sampling can be conducted to identify specific contaminants and to collect geologic samples as needed.

Tank Farms Vadose Zone Baseline Characterization

The tank farms vadose zone baseline characterization program was created primarily to support tank operations. The Resource Conservation and Recovery Act specifies requirements to identify sources of contamination and determine the nature and extent of the contamination that leaked from the single-shell tanks. The characterization program performed that function at the single-shell tank farms in a limited way. The program also established a baseline for tank monitoring and leak detection. Future data can be compared to baseline information to identify changes in vadose zone contamination resulting from the addition or migration of contaminants. The technical plan for this baseline characterization program is documented in DOE (1995f), and the program management plan is provided in DOE (1995g).

A typical tank farm is shown in plan view in Figure 3.3.1 and consists of a collection of from 2 to 18 underground tanks. Most of the tanks are surrounded by monitoring boreholes, which provide access to the subsurface with geophysical logging probes. There are 12 single-shell tank farms at Hanford that contain a total of 149 tanks. There are also 6 double-shell tank farms at Hanford that contain 28 double-shell tanks. However, because no double-shell tanks have ever leaked, the vadose zone baseline characterization project only concerns the single-shell tanks.

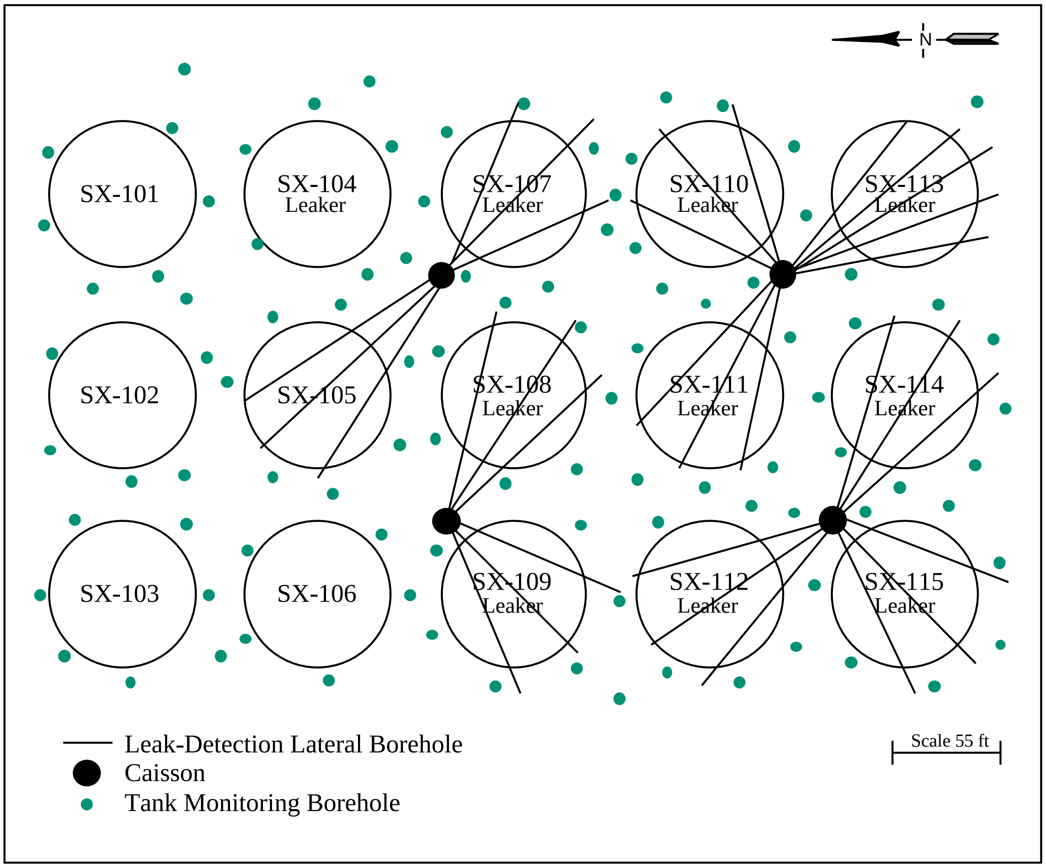

Figure 3.3.1. Plan View of Single-Shell Underground Waste Storage Tanks in a Hanford Tank Farm

The baseline characterization program involved assaying gamma-emitting radionuclides in the vadose zone around the single-shell tanks. The radionuclides were assayed by logging boreholes near the tanks with calibrated spectral gamma-ray logging systems. The spectral gamma-ray logging systems used high-purity germanium detectors configured to operate in boreholes and calibrated to quantify concentrations of gamma-emitting radionuclides in the sediment. These data were used for a general determination of the nature and extent of contamination.

In 1996, the characterization was limited to the spectral gamma-ray logging assay of existing boreholes. There are a total of 758 boreholes surrounding 134 single-shell tanks. The intent was to extract as much information as possible from the boreholes to produce a basic understanding of contamination distribution. This assay method is a relatively low-cost screening method for obtaining preliminary data and can also be used to help identify areas requiring further characterization.

Once the baseline characterization is complete, more comprehensive characterizations focusing on significant areas of contamination can begin. The characterizations can be used to determine the distribution of nongamma-emitting radionuclides (i.e., technetium-99 or uranium), which are not determined under the current program.

Following data collection activities, a vadose zone monitoring summary report was prepared for each tank. Each tank summary data report provided logs of gamma-emitting radionuclide concentrations (Figure 3.3.2) as well as logs of naturally occurring potassium-40, thorium-232, and uranium-238. The report also contained summarized historical information about a tank, such as any occurrence reports or leak history, and provided an analysis and interpretation of the historical gross gamma log data. Each report identified sources of vadose zone contamination, when possible, and provided recommendations for monitoring or future characterizations.

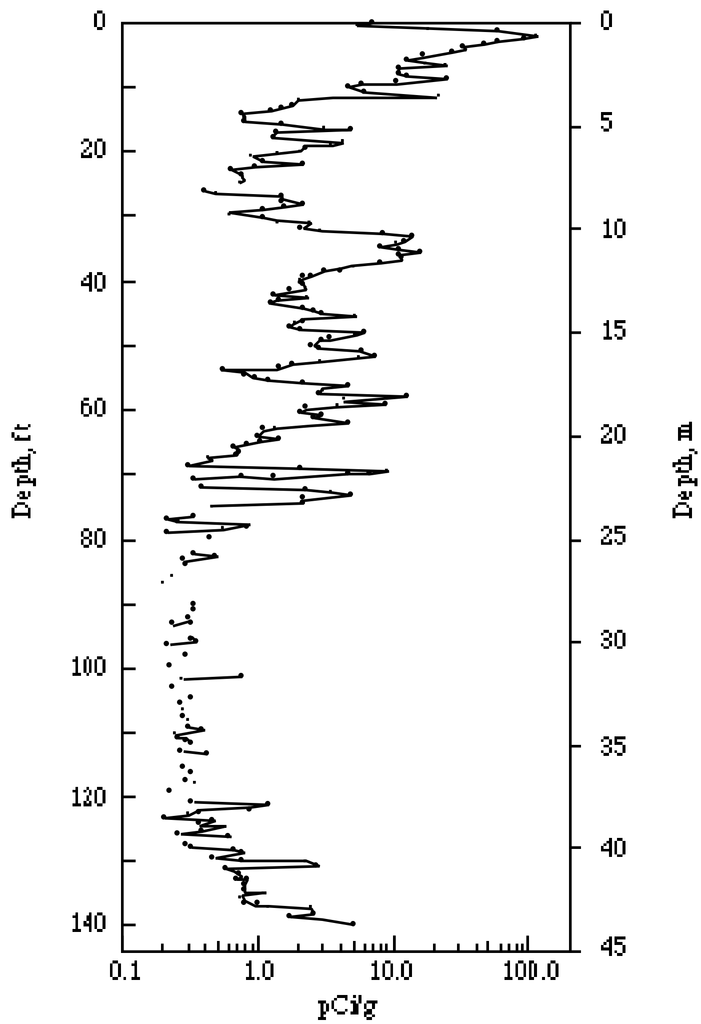

Figure 3.3.2. An Example of a Gamma-Emitting Radionuclide (cesium-137) Concentration Log (borehole 41-02-02)

After completion of a tank summary data report for each tank, a more comprehensive tank farm report was prepared. Each tank farm report provided a correlation of the contamination across the tank farm and included computer-generated visualizations of the contamination. Correlations among boreholes help to determine contamination sources and define the three-dimensional distribution. The visualizations are based strictly on an empirical geostatistical correlation of the data and are used by operations personnel to understand the current distribution of contamination and to identify potential monitoring targets. The report also provides a tank-by-tank review of previous conclusions in the tank summary data reports to reevaluate any inferred contamination sources around each tank.

Data Collection and Analysis

All data acquisition is accomplished with the spectral gamma-ray logging system, which is basically a laboratory quality gamma-ray assay system automated and configured to deliver a germanium detector down a borehole. Data acquisition operations are specified by logging procedures provided in DOE (1995h) and governed by quality assurance procedures specified in DOE (1996i). All data are managed as quality records governed by a records management plan (DOE 1995i); data management is regulated by a quality assurance plan (DOE 1996i).

The spectral gamma-ray logging system equipment was calibrated with a comprehensive base calibration and biannual field calibrations specified in a calibration plan (DOE 1996j). The base calibration was accomplished using borehole model standards constructed at the DOE Grand Junction Office specifically for borehole logging. The calibration models meet the national uranium counting standards and are certified by the New Brunswick Laboratory (Leino et al. 1994). The base calibration is reported in DOE (1995j). Biannual field calibrations are conducted using borehole calibration models installed at Hanford. The results of these calibrations are reported in biannual reports (e.g., DOE 1996k).

Data analysis involves identifying the specific isotopes detected in the gamma-ray spectra and then calculating the concentrations of those isotopes. Once the isotope concentrations are determined, the data are collated into an isotope-specific log of the radionuclide concentration versus depth, and the data are plotted as a log. Logs of manmade and naturally occurring radionuclides are produced routinely. Details of the data analysis process are documented in a data analysis manual (DOE 1996l).

Data are interpreted by reviewing all the spectral gamma-ray logging system logs from a single borehole and correlating the data with information about the geology, tank history, and historical gross gamma logs. The intent of the individual borehole interpretations is to quantify contamination plumes, identify any obvious contamination sources, and relate contamination distribution patterns to tanks or geology. The origin and cause of the contamination distribution can often be identified by reviewing the current contamination profiles and historical gross gamma logs.

Results for 1996

Baseline Logging and Tank Summary Data Reports

During 1996, borehole geophysical logging operations continued and data acquisition from 234 boreholes surrounding 44 tanks was completed. The boreholes surrounding the tanks in the AX Tank Farm in the 200-East Area and S, TX, and TY Tank Farms in the 200-West Area were logged and all boreholes surrounding four of the tanks in the A Tank Farm (200-East Area) were logged.

Also during 1996 tank summary data reports were completed for all the tanks in the BY Tank Farm (200-East Area), tanks SX-112 through SX-115, six tanks in the TX Tank Farm, and all tanks in the U Tank Farm (200-West Area). Tank summary data reports for tanks SX-101 through SX-111 (200-West Area) were completed in 1995. The tank summary data reports published in 1996 are DOE (1996m through 1996tt).

Activities Related to the SX Tank Farm

The SX Tank Farm in the 200-West Area was frequently the focus of the vadose zone baseline characterization program during 1996. In January 1996, the results and conclusions in the tank summary data reports revealed that cesium-137 contamination from tank leaks had migrated deep into the vadose zone. Cesium-137 contamination was detected at relatively high concentrations deeper than expected (as deep as 38.1 m [125 ft]) in several boreholes. It was previously believed that cesium-137 was relatively immobile in the sediment and that it would migrate only a few meters (feet) from the base of the tanks.

A preliminary review of groundwater contamination data raised questions about the true source of a technetium-99 plume that appeared to originate from the S/SX Tank Farm complex. An extensive review of groundwater monitoring data was conducted by Hanford personnel, and it was determined that the S/SX Tank Farm complex was contributing technetium-99 and chromium to the groundwater. This conclusion was later confirmed in an independent investigation by the Washington State Department of Ecology. As a result, a groundwater assessment order was issued by the Washington State Department of Ecology for the S/SX Tank Farm complex and a groundwater assessment plan was prepared (Caggiano 1996).

The SX Tank Farm report, the first to be produced at Hanford, was completed in 1996 (DOE 1996uu). The report provides the visualizations of the cesium-137 contamination distributed in the sediment beneath the tanks; an example is provided in Figure 3.3.3. The visualizations were developed from an empirical geostatistical correlation of the borehole log data and are subject to the uncertainties of the data. In effect, the visualizations are only valid to the extent that the borehole log data match what is actually in the formation. For example, the visualizations include several known “false plumes” that are the result of some boreholes being contaminated by wind-blown materials. The suspected false plumes are identified in the tank farm reports. Of greater concern was the fact that the visualizations might be biased by the possibility that contamination migrated up or down the borehole along a gap that potentially exists between the outside of the borehole casings and the sediment. That gap is formed by the cable-tool drilling method that was used to

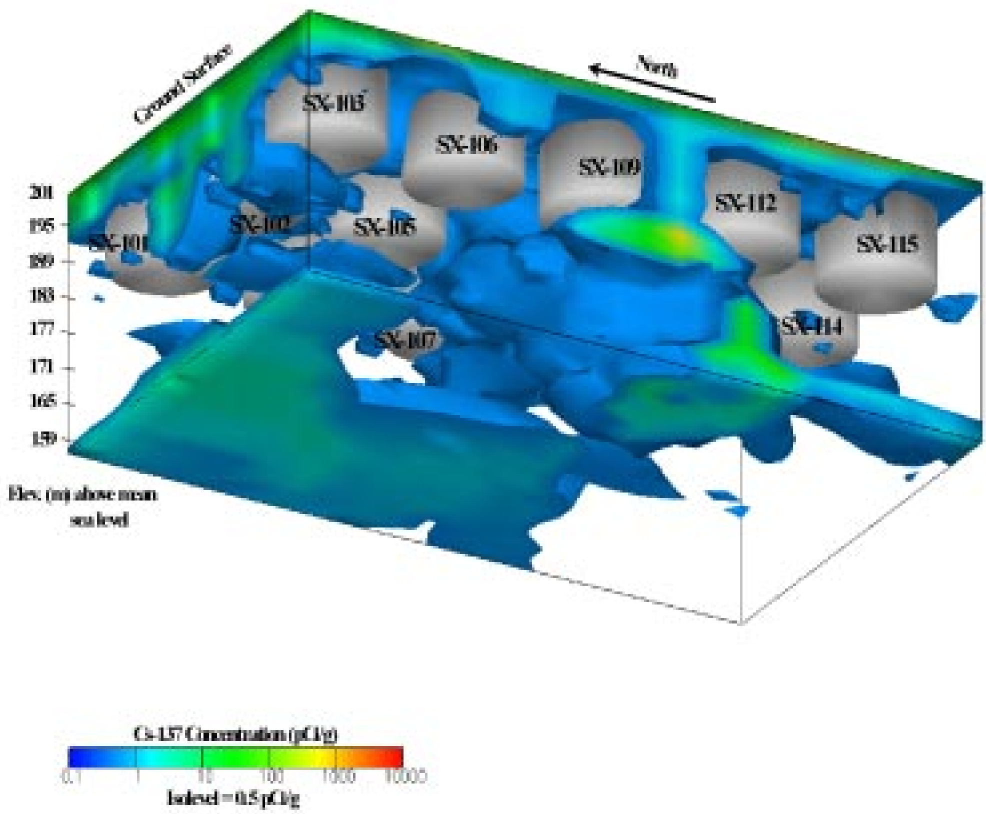

Figure 3.3.3. A Visualization of Cesium-137 Contamination Beneath the SX Tank Farm. Groundwater elevation is 145 m (476 ft).

install most of the monitoring boreholes. It is possible that the sediment was cohesive enough that it did not collapse back around the borehole casing after a borehole was drilled or that significant collapse zones developed in the sediment formation during drilling that produced large voids at depth.

Concerns that the contamination detected deep in the vadose zone at the SX Tank Farm was not actually in the formation but merely the result of contamination moving down the gap between the sediment and the outside of the borehole casings prompted DOE to form an independent panel of experts to perform an assessment of the data. This assessment included reviewing the data and recommending a course of action to confirm or refute the findings of the vadose zone logging characterization work as published in the tank summary data reports. Under the guidance of the independent panel, two new boreholes were drilled in the SX Tank Farm. However, instead of using a cable-tool drilling method as was used to construct the old boreholes, a percussion hammer drilling method was employed in an effort to minimize drag down of contamination and thereby determine if the contamination is really in the formation and not simply a borehole effect.

These boreholes were also drilled and logged in successive 3.05-m (10-ft) increments to quantify the amount of contamination being dragged down.

The first borehole (41-12-01) did not intercept a plume of high contamination as expected. The cesium-137 concentration logs showed increases with each successive 3.05-m (10-ft) drilling increment, demonstrating contamination was being dragged down during drilling.

The second borehole (41-09-39) was located 1.65 m (5.4 ft) from an older borehole (41-09-04). Before drilling the second hole, a modification was made to the drill stem that was not made on the first borehole. A small weld lip on the bottom of the casing was ground smooth in an attempt to minimize contamination drag down. As a result, contamination drag down did not occur. This borehole was drilled and logged in the same 3.05-m (10-ft) successive increments as borehole 41-12-01. The successively deeper logs did not show evidence of contamination drag down; therefore, it is assumed that the modifications to the drill stem successfully eliminated drag down.

Borehole 41-09-39 intercepted relatively high levels of contamination to a total depth of 39.62 m (130 ft), confirming the presence of cesium-137 contamination in the formation to that depth. The relatively high cesium-137 concentration at depth, with little to no contamination from drag down, confirmed that contamination is present within the formation deep in the vadose zone and that the borehole was not the primary pathway for contamination migration. The pattern of cesium-137 concentrations in borehole 41-09-39 closely matched the pattern in adjacent borehole 41-09-04, suggesting that the lithology had a significant influence on the migration and deposition of the cesium-137 contamination and providing additional evidence that the cesium-137 contamination had migrated through the formation and not simply along an unsealed borehole.

Finally, as a part of the vadose zone investigation, four tanks in the SX Tank Farm were reevaluated to reassess the volume of contamination that leaked from the tanks. Historical leak models were developed for tanks SX-108, SX-109, SX-111, and SX-112 by the Los Alamos National Laboratory. Table 3.3.1 provides the old leak volume estimates as published in Hanlon (1996) along with the new estimates provided by the Los Alamos National Laboratory.

For three of the four tanks, the new leak volume estimates are over 10 times as high as the previous estimates, demonstrating a need to reassess the leak volume estimates for all of the single-shell tanks.

The initial conclusions and recommendations of the independent expert panel were provided in December 1996 as a three-page draft statement. A final report by the panel was released in early 1997 (Conaway et al. 1997).

Table 3.3.1. Leak Volume Estimates for Tanks SX-108, SX-109, SX-111, and SX-112

Tank	Old Estimate, L (gal)	New Estimate, L (gal)
SX-108	132,000 (35,000)	770,000 (203,000)
SX-109	38,000 (10,000)	420,000 (111,000)
SX-111	7,600 (2,000)	235,000 (62,000)
SX-112	113,000 (30,000)	216,000 (57,000)

Activities Related to the BY Tank Farm

Sixty-nine boreholes surrounding the 12 tanks in the BY Tank Farm in the 200-East Area were logged with the spectral gamma-ray logging systems from July through September 1995. The final tank summary data report for the BY Tank Farm was issued in April 1996 (DOE 1996x). The BY Tank Farm report was issued in early 1997 (DOE 1997d).

Log data were analyzed by identifying the manmade contaminants and calculating the equivalent concentration of a uniformly distributed contaminant. Plots of the contaminant concentrations as a function of depth were prepared for each borehole and were included in the appendixes of the corresponding tank summary data reports.

Potassium-40, thorium-232, and uranium-238 concentrations were also calculated and presented in log formats similar to those used with manmade radionuclides. These data were correlated with lithological information to determine if distinguishable lithologic features are present in the vadose zone beneath the BY Tank Farm and to determine how these features may have contributed to the distribution of the contamination below the tanks.

The spectral gamma-ray log data show cesium-137 is the most abundant and highly concentrated gamma-emitting manmade radionuclide in the vadose zone at the BY Tank Farm. Cobalt-60 was also detected in fairly extensive distributions but at much lower concentrations than cesium-137. Cobalt-60 contamination was often detected at the bottoms of boreholes. Figure 3.3.4 is a visualization of cesium-137 and cobalt-60 contamination in the vadose zone around tanks in the BY Tank Farm. Other gamma-emitting radionuclides detected were antimony-125 and europium-154.

The highest cesium-137 concentrations in the BY Tank Farm were detected adjacent to tank BY-103, which is designated an assumed leaker. Figure 3.3.5 shows the contamination in the vadose zone in the vicinity of tank BY-103. Other high cesium-137 concentrations were detected near the surface in thin zones and appeared to be related to surface spills, pipeline leaks, or the proximity of the boreholes to pipes containing contamination. Cesium-137 was detected throughout the lengths of several boreholes, but concentrations were usually less than 1 pCi/g.

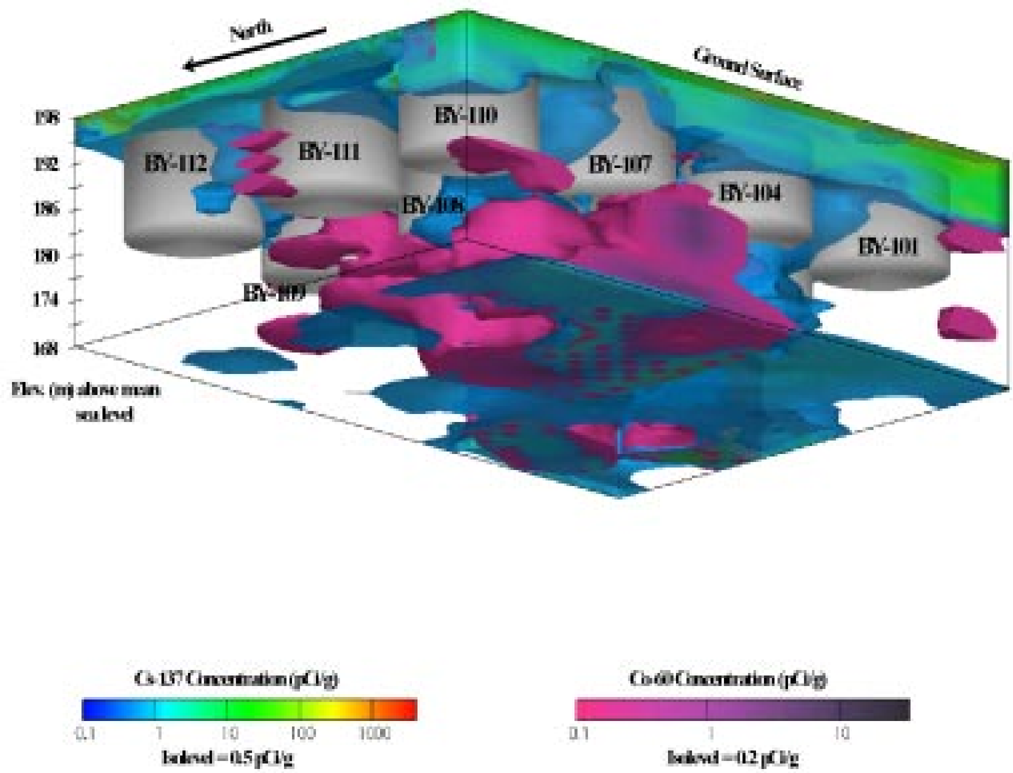

Figure 3.3.4. A Visualization of Contamination in the Vadose Zone at the BY Tank Farm (cesium-137 shown transparent). Groundwater elevation is 125 m (402 ft).

Cobalt-60 was detected around all the tanks in the BY Tank Farm that are known to have leaked. The cobalt-60 concentrations were usually less than 10 pCi/g; however, vertical distributions were extensive. Cobalt-60 was often detected above the bases of the tanks and near the ground surface. The near-surface cobalt-60 was often associated with zones of elevated near-surface cesium-137 contamination, indicating sources from surface spills or pipeline leaks.

A majority of the boreholes in the BY Tank Farm extend to a depth of approximately 30.5 m (100 ft), and the log data from several boreholes indicate significant cobalt-60 concentrations at the bottoms of the boreholes. Cobalt-60 was detected at the bottom of the deepest borehole logged (44 m [145 ft]). The maximum depth extent of the cobalt-60 contamination in the BY Tank Farm is not known; therefore, any impacts of vadose zone contamination on groundwater cannot be directly determined. The depth to groundwater beneath the BY Tank Farm is approximately 76.2 m (250 ft), which is significantly deeper than any of the tank monitoring boreholes.

The presence of cobalt-60 beneath the southern portion of tank BY-110 raises questions concerning the integrity of this tank. Historical documentation reveals evidence of a potential for leakage (i.e., tar rings and unexplained liquid-level decreases); however, neither this information nor the spectral gamma-ray data confirm leakage from this tank.

Tank BY-111 is presently designated a sound tank. Cobalt-60 contamination on the west side of tank BY-111 indicates that this tank has leaked in the past. Historical documentation records liquid-level decreases coinciding with increases in gamma-ray intensities in monitoring boreholes around the west side of this tank. On the basis of this information, it was recommended that this tank be reclassified an assumed leaker.

The potassium-40, thorium-232, and uranium-238 spectral data and the geologic data show good correlation at the contact between the Hanford formation upper gravel sequence and the Hanford formation fine sequence. This contact occurred at approximately 14.63 m (48 ft) in the

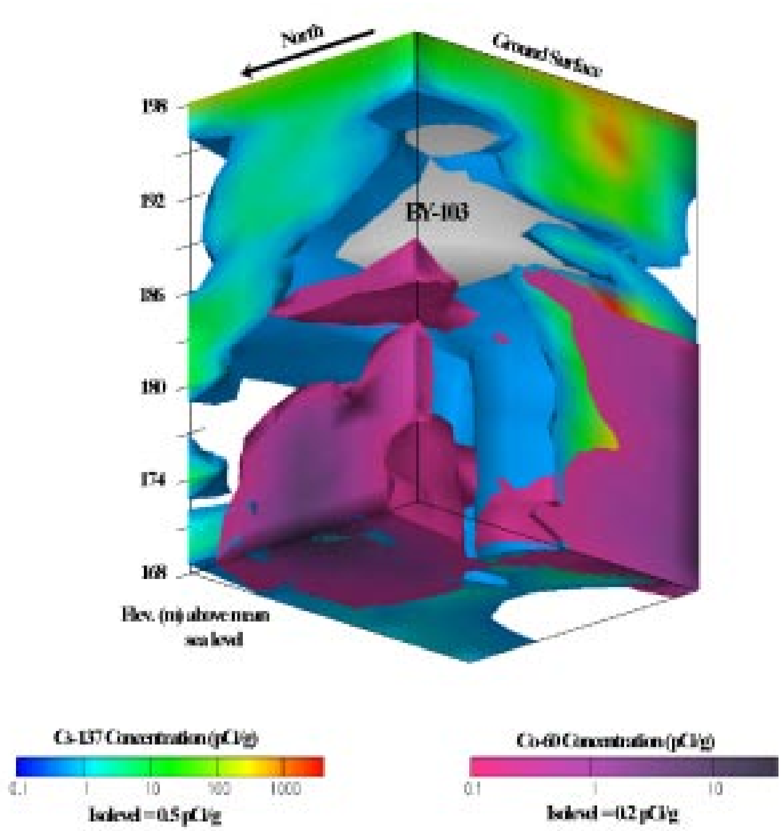

Figure 3.3.5. A Visualization of Contamination in the Vadose Zone at Tank BY-103. Groundwater elevation is 125 m (402 ft).

eastern portion of the BY Tank Farm and is as deep as 18.29 m (60 ft) in the western portion of the tank farm. This contact was distinct in some boreholes; in others it was gradational. The contact may provide a preferential migration pathway for contamination from the tank. No other features were correlatable among boreholes.

Other Tank Farms Baseline Characterization Activities

A new passive spectral gamma-ray logging system was constructed in 1996 for use as a vadose zone contamination monitoring system. This leak verification and monitoring system was designed to rapidly provide an accurate contamination concentration log from previously identified contamination zones.

The new system consists of a basic spectral gamma-ray logging system with three separate sodium-iodide detector probes of differing efficiencies. The three probes are designed to provide a measurement capability over a large dynamic range of contamination concentrations. The sodium-iodide detectors used for the leak verification and monitoring system are much easier to use than the germanium detectors on the spectral gamma-ray logging systems because they do not require cooling to liquid nitrogen temperatures; however, they do not provide the high-energy resolution of a germanium detector that is needed to identify the specific radionuclides. Nevertheless, assays can be highly accurate and precise if a baseline was already established with a germanium detection system.

The leak verification and monitoring system will be used to quickly assay boreholes surrounding tanks suspected of leaking. Although the system will not provide a primary leak-detection method, it can be used to verify that a tank is leaking if new contamination is detected in boreholes surrounding the tanks. The leak verification and monitoring system will also be used to monitor regions where previous gross gamma data show the contamination is moving.

Spectral gamma-ray shape-factor analysis methods were also developed in 1996. These methods allow an analyst to determine the approximate distribution of contamination around a borehole by studying the shape of the gamma-ray spectra from the germanium logging system. The shape-factor analysis method was developed by performing nuclear transport modeling simulations to determine the sensitivity of various spectral parameters to extremes in source distribution. Additional required nuclear transport model simulations will be performed in 1997, and the simulation models will be validated with actual field measurements at the DOE Grand Junction Office borehole calibration facility.

Characterization of Historical Effluent Disposal Sites

Radioactive and hazardous wastes disposed of to the soil column have been the dominant contributors to groundwater contamination at the Hanford Site. Even though disposal of untreated waste water to the ground stopped in 1995, movement of contaminants in the soil column beneath historical effluent disposal sites can still occur. Wastes in the soil column at historical effluent disposal sites at Hanford have been found in the vadose zone and are potential contributors to additional groundwater contamination.

Historically, large volumes (1.6 trillion L [426 billion gal]) of low-level liquid waste were discharged to surface ponds and ditches. Smaller volumes of low- and intermediate-level liquid wastes (53 billion L [14 billion gal]) were discharged to the subsurface in reverse wells, french drains, cribs, and tile fields.

Prior to the mid-1970s, over 450 million L (120 million gal) of high-level liquid wastes were discharged to the vadose zone via cribs and french drains from underground storage tanks containing high-level wastes. The estimated total quantity of radioactive waste was over 65,000 Ci (decayed through December 1989). The high-level radioactive waste that could not be discharged to the environment was transferred to the underground storage tanks. High-level radioactive waste could exceed concentrations of 100 µCi/mL (Routson 1973).

Although ground disposal of untreated wastes has been terminated, the residual contaminated liquid remaining in soil pore spaces following drainage of free liquid at these sites can continue to be a long-term source of groundwater contaminants, especially if a source of moisture (liquid) is available to transport the mobile waste constituents (e.g., enhanced natural infiltration from the coarse gravel coverings, removal of vegetation, leaking water lines, etc.).

Monitoring Results

A recent monitoring survey at the BY Cribs in the 200-East Area with a spectral gamma-ray detector confirmed that the majority of the contamination at the facility is stable and is not continuing to migrate to the groundwater. However, a narrow interval (4 m [13 ft]) within the cobalt-60 contamination plume is migrating, as shown by an unexpected 20% decrease in concentration at a depth of approximately 37.5 m (110 ft). This decrease is apparent when comparing monitoring data collected in December 1994 to baseline data obtained in September 1991 (Figure 3.3.6).

Cesium-137 was not expected to migrate more than 10 m (32.8 ft) below the discharge location except through nonnatural pathways. An example to the contrary was found at the 216-T-19 Crib in the 200-West Area. Monitoring well 200-W15-4 was drilled 20 m (66 ft) from the crib 6 years after discharges to the crib were terminated. A gamma-log survey (Figure 3.3.7) shows the main contaminant plume from the crib at a depth of 12 m (39 ft) with a maximum concentration of more than 33,000 pCi/g. A second cesium-137 contamination interval is located at a depth of 46 m (151 ft) and averages 6 pCi/g. This example was chosen because it shows that the contamination did not migrate down the borehole and was not smeared by the drilling activities. There is currently insufficient information to identify the migration method. The contamination at 47 m (154 ft) suggests that a small fraction of the cesium-137 is not adsorbed onto the soil sediments at the release point (as expected) and has a low soil-retention factor.

Electrical resistivity tomography is a three-dimensional geophysical imaging technique that can map liquids migrating through the vadose zone. Two field tests were recently conducted at a mock tank site. One test was to demonstrate applicability, the second test was to demonstrate alternate sensor deployment. The first test monitored the migration of a liquid solution to a depth of 10.7 m (35 ft) in 5 days. The second demonstration incorporated electrode arrays installed with cone penetrometers. The equipment monitored the migration of a brine solution to a depth of 30.4 m (100 ft) in 12 days. The results of both tests implied that if the leak rate continued, the groundwater at 76.8 m (252 ft) would be impacted in 36 days.

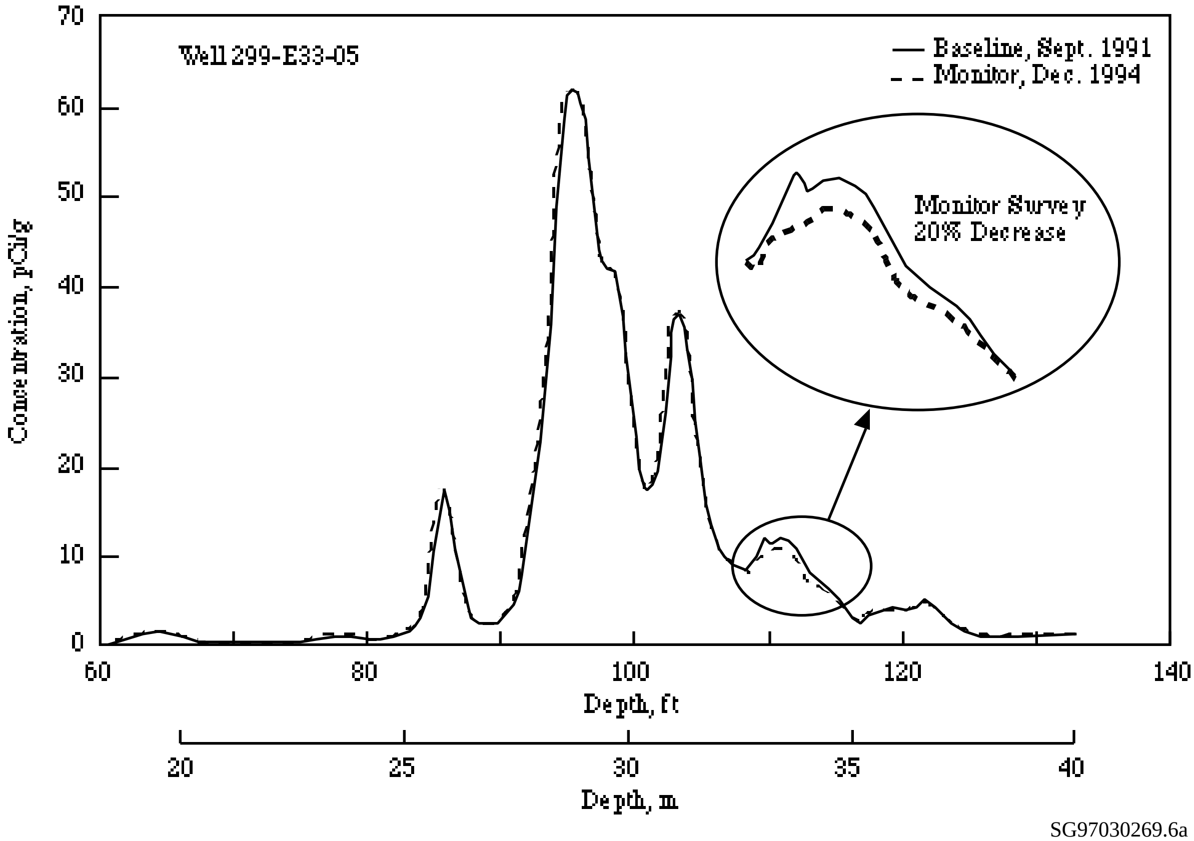

Figure 3.3.6. Concentrations of Cobalt-60 in Vadose Zone Sediments at the BY Cribs, 200-East Area, 1991 and 1994 Data

There is growing evidence that small-volume leaks (approximately 100,000 L [26,420 gal]) and the downward movement of contaminants with high soil-retention factors (cesium-137) can impact the groundwater. This evidence has resulted in efforts to reevaluate contaminant transport models.

Historical discharge of liquid waste to cribs and tile fields in the Plutonium Finishing Plant area resulted in accumulation of an estimated 20,000 Ci of transuranic waste, plutonium-239, and americium-241. On the basis of relative hazard, the Plutonium Finishing Plant cribs are some of the most significant sources of radioactive contamination in the vadose zone at the Hanford Site. Concentrations of transuranic wastes in the soil extend to depths of 30 m (98.4 ft) (Figure 3.3.8). The combination of high acidity and the presence of complexants apparently allowed the transuranic wastes to penetrate deeper into the soil column than expected. Evidence of stability or continued plume migration will be monitored over time by periodic logging in the available boreholes with high-resolution spectral gamma-ray equipment.

A more detailed summary, including original references, of the vadose zone investigations at historical liquid waste disposal sites is provided in Gleckler (1997).

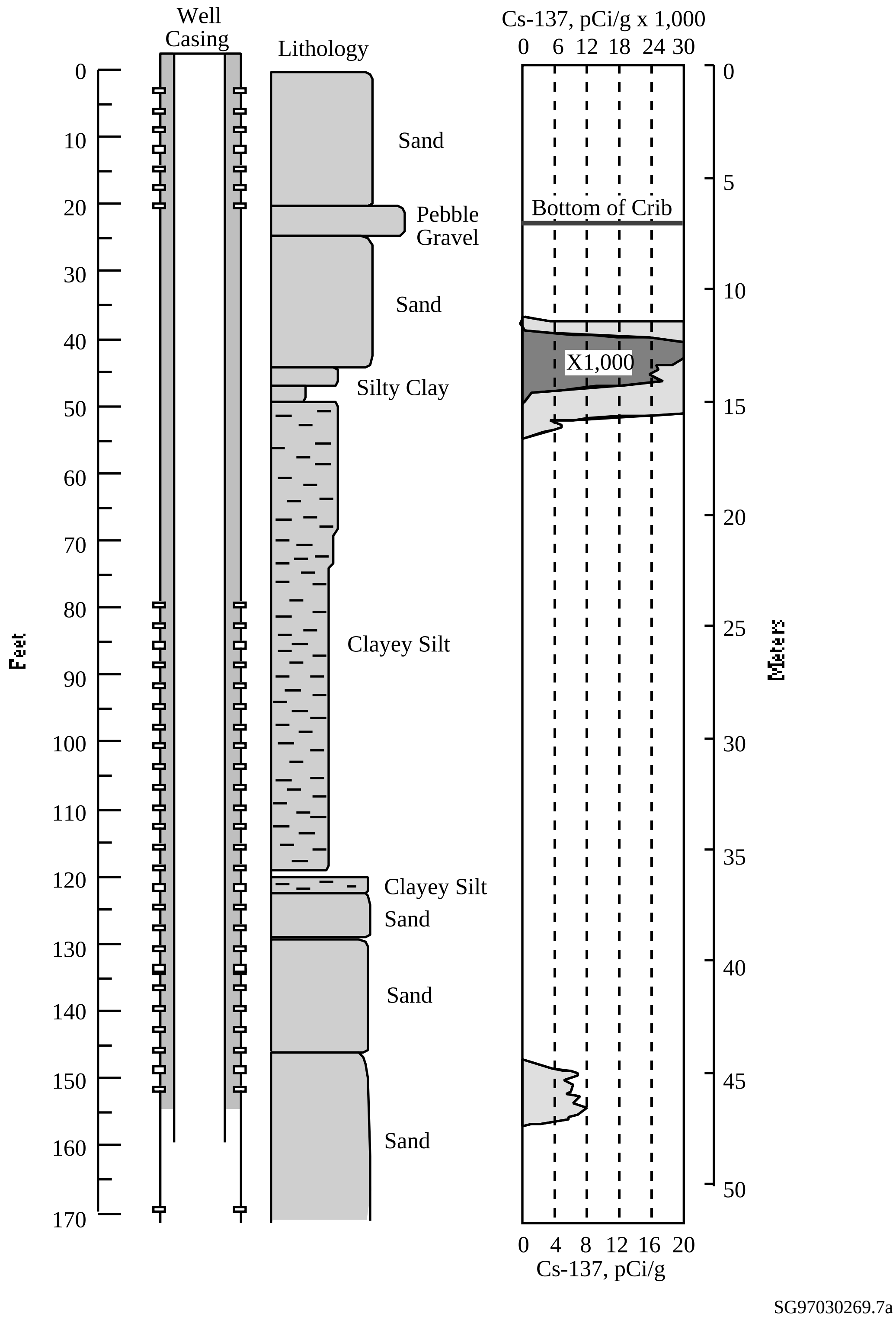

Figure 3.3.7. Stratigraphy and Gamma-Log Survey Plot for 216-T-19 Crib, 200-West Area

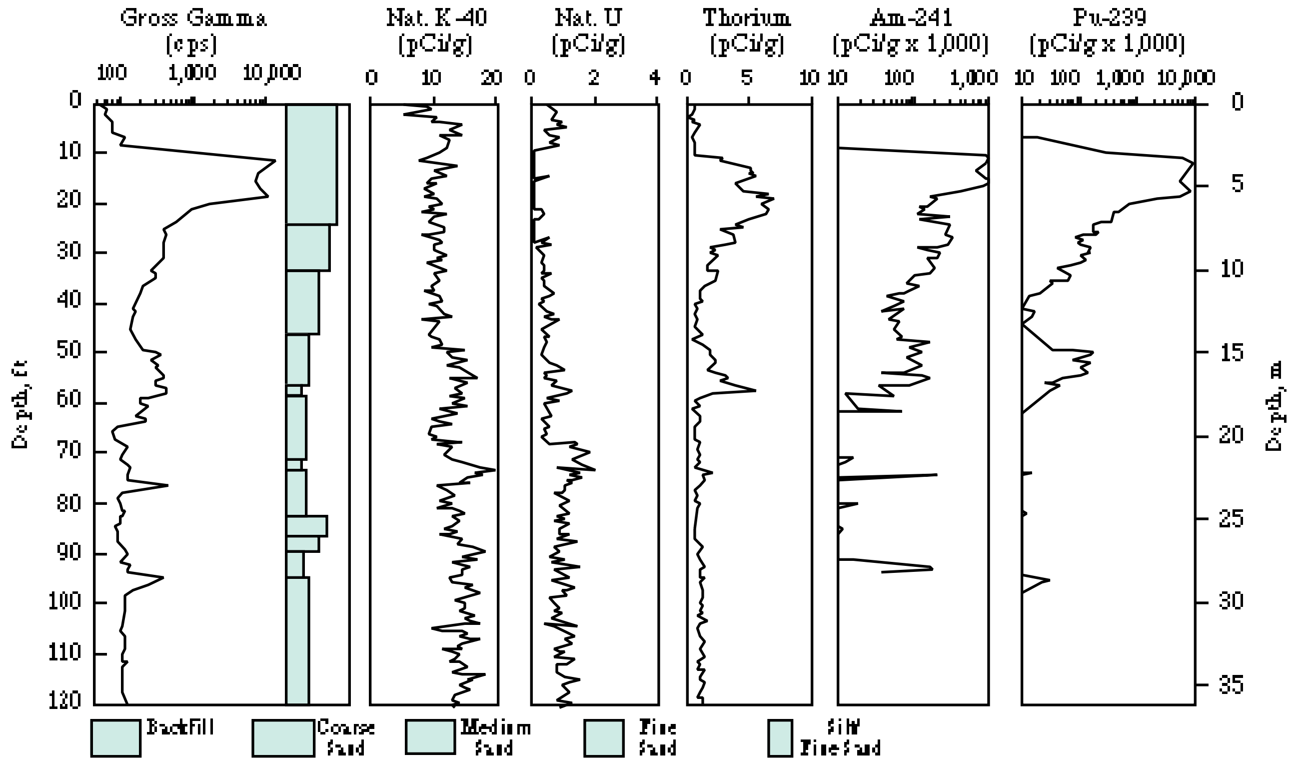

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Figure 3.3.8. Logs of Radionuclides in Vadose Zone Sediments Beneath the 216-Z-1A Crib Near the Plutonium Finishing Plant, 200-West Area, 1993